STABILIZED OPERATION MODE OF LASER ION SOURCE USING PULSED MAGNETIC FIELD

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Abstract

Laser ion source produces many types of ions with the electron beam ion source for experiments in Brookhaven National Laboratory. One laser and steady solenoidal magnetic field were used in the last run. For next run, we will employ two laser at the same time to improve the beam stability. In addition, we will use a pulsed magnetic field to control the beam profile flexibly. We measured the beam current at several points from the laser ion source to the following booster ring to compare the beam stabilities between the last and next run settings. The ratio of the standar deviation to the mean value of the total charge within a single beam pulse was found to be smaller at all measurement points with the next run setting.

INTRODUCTION

Many types of ion species are used for nuclear physics experiment at Relativestic Heavy Ion Collider and cosmic ray simulation at NASA Space Radiatoin Laboratory in Brookhaven National Laboratory. The ions are provided by the laser ion source (LIS) and the electron beam ion source (EBIS). Figure 1 shows the layout of the injector line. Singly charged ions are injected from the laser ion source into the EBIS where the ions are ionized to highly charged states. The ions are accelerated by RFQ accelerator and IH linac to 2 MeV/u, and then injected to the booster ring through the bending magnet.

In the laser ion source, the plasma is prduced by laser ablation process in vacuum chamber and then drifts to the extraction electrodes through the dirft section where the plasma extendes to a certain width that detemines the pulse width of the extracted beam. In the last run, one laser pulse for one beam pulse and 3 m solenoid to guide the plasma were used. The carbon beam was not stable compared with other species. The cause might be that the laser energy was as small as the ablation threshold and the solenoidal magnetic field was strong to meet the requirement of the higher beam currents than the design value. For the next run, we will employ two laser pulses at the same time to increase the laser energy. In addition, we intalled a coil to produce pulsed magnetic field for more flexible control of the plasma and the beam profile while the steady solenoidal magnetic field will be decreased or not used. The purpose of this study is to examine whether the beam stability is improved with the next run setting. We measured the beam current at the current transformer 1 (CT 1), CT 2, CT 3, and the Faraday cup as shown in Fig.1. Then we compared the standard deviation of the total charge within a single beam pulse.

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DEVICES IN INJECTOR LINE AND THE EXPERIMENTAL CONDITIONS

Laser Ion Source

Figure 2 shows the schematic of the laser ion source. The detail is described in the reference [1]. Several types of solid targets placed in the vacuum chamber are irradiated with laser (Quantel Brilliant B TWINS, 1064 nm, 6 ns). Between the target and the extraction electrodes, the 3 m long solenoid used in the last run and the coil that will produce pulsed magnetic field from the next run are placed. The specifications of the magnets are shown in Table 1. The coil current is driven by a pulsed circuit composed of 7.5 μF capacitor to rise the magnetic field during the time when the plasma passes through the coil. The equivalent circuit is shown in Fig.3. The current in the coil as a function of time is shown in Fig. 4.

Table 1: Magnet specificatons used in laser ion source

	Last run	Next run
Magnet length	3 m	45 mm
Inner diameter	76 mm	80 mm
Turns	5728	330
Time structure	Steady	7 μs rise time

For the experiment, graphite was used as target. As the last run settings, single laser with the energy of 550 mJ and 3 m long solenoid with the magnetic field of 2.3 mT were used. Meanwhile, as the next run settings, we irradiated the same spot on the target at the same time with two laser pulses. The total energy was 920 mJ. The pulsed magnetic field was triggered at the laser irradiation. The maximum field was 9.0 mT. For both case, the laser spot size was 0.10 cm^2. The platform voltage of the laser ion source was 19 kV with respect to the laboratory ground, and the intermediate electrode votage for extraction was -3.5 kV with respect to the platform voltage.

Electron Beam Ion Source

As explained in the reference [2], the EBIS is mainly composed of electron gun, high voltage tubes, and superconducting solenoid. The gun immersed in a mangetic field has capability of producing current upto 20 A. The electron beam goes through the high voltage tube that is sorrounded by the solenoid with the magnetic field of 5 T. The diameter of the electron beam in the tubes is adjusted by changing

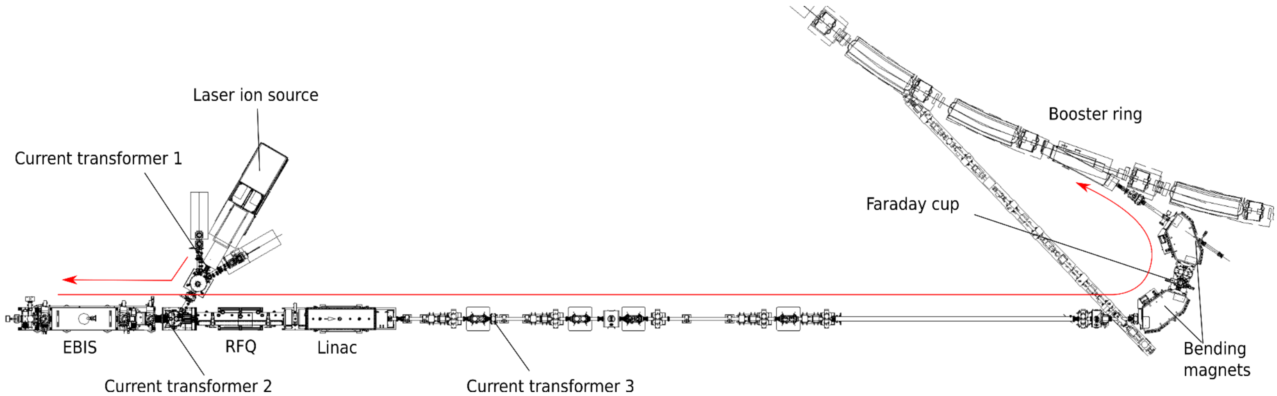

Figure 1: Layout of the injector line.

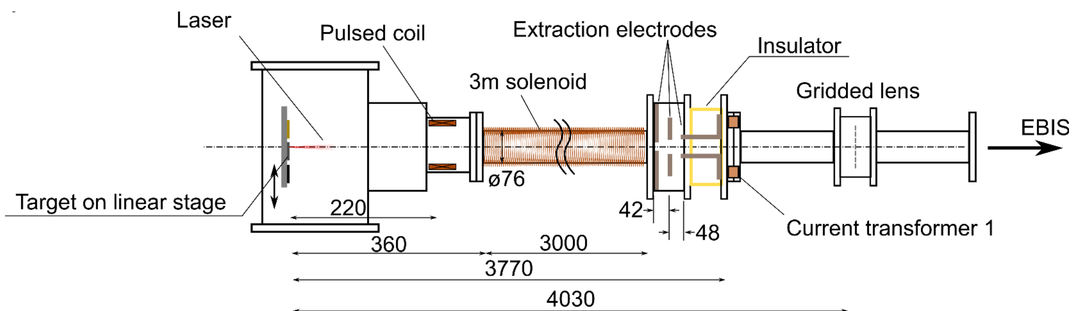

Figure 2: Shematic of the laser ion source.

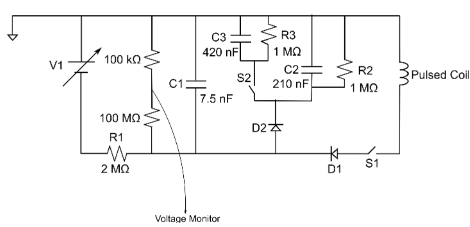

Figure 3: Diagram of equivalent pulsed circuit.

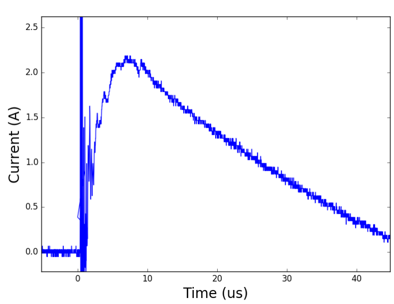

Figure 4: Current in the coil for pulsed magnetic field.

the magnetic field at the gun. The ions are injected into the tubes and trapped by the electric field of the tubes and the electron beam. During the trap, the ions are ionized by the electron beam. The trap time determines the charge state of the ions. Then, the ions are extracted to the downstream. For the experiments, the current density of electron beam was 230 A/cm^2 in the tubes. The trap time was adjusted to maximize the abandunce of C^{5+}.

RFQ Linac and IH-linac

The details are described in the paper [3]. The operational frequency of the both linac is 100.625 MHz. The ions are accelerated by the 4-rod RFQ linac from 17 keV/u to 0.3 MeV/u, and then to 2.0 MeV/u by the IH-linac. The ions are transported and injected into the booster ring through the bending magnet. For the experiments, the devices were adjusted to maximize the abandunce of C^{5+}.

Current Monitors

We used three current transformers and a Faraday cup as shown in Fig.1 to measure the beam current. The current trasformer 1 is placed right after the extraction electrodes of the laser ion source. The current transformer 2 is in front of the entrance of the electron beam ion sourse to measure the beam current at the injection into and extraction from the ion source. The current transformer 3 is placed after the quadrupoles following the IH-linac. The Faraday cup is between the bending magnets where almost one types of ions are detected.

RESULTS

Figure 5(a) and 5(b) show the beam current measured at the exit of the laser ion source with the current transformer 1. The horizontal axis is the time from laser shot. The current in Fig. 5(a) was taken with double lase pulse and the pulsed magnetic field with the next run setting, while the current in Fig. 5 (b) was taken with singe laser pulse and the steady field with the last run setting. In both figures, 5 waveforms

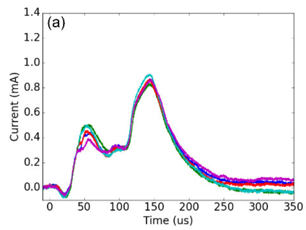

Figure 5: Beam current waveforms measured after the exit of the laser ion source with the current transformer 1 using double laser poulse and pulsed magnetic fied (a), and single pulse and steady solenoid (b).

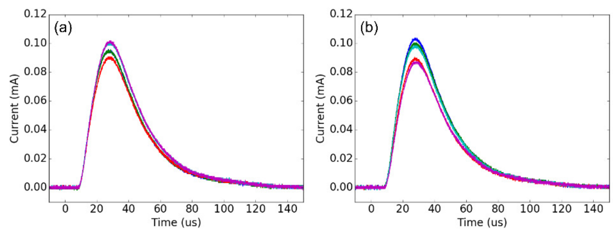

Figure 6: Beam current waveforms measured at the bending magnet with the Faraday cup using double laser poulse and pulsed magnetic fied (a), and single pulse and steady solenoid (b).

taken under the same condition are overlaid. In Fig. 5(a), there were two peaks at 50 µs and 150 µs. Typically, the beam current waveform has one peak because of the thearmal velocity distribution [4] if magnetic field are not applied. The first peak at 50 µs in Fig. 5(a) corresponds to the typical peak. Highly charged ions or lighter ions exists in the faster part around the peak. On the other hand, the peak at 150 µs was made by the pulsed magnetic field. Slower part in the beam is mainly composed of the singly charged ions, and thus one can increase the current of the signly charged ions in the slower part with the pulsed magnetic field. The beam composed of the singly charged ions is suitable for the electron beam ion sources. By comparing the waveforms in Fig.5(a) and 5(b), such as peak hight and pulse width, one can find that the reproducibility of the beam current in Fig.5(a) is more stable than the other. This shows that the beam produced with double laser pulse and pulsed magnetic field is more stable.

Figure 6(a) and 6(b) show the beam current waveforms as a function of time at the bending magnet with the Faraday cup. The waveforms in Fig. 6(a) with double laser pulse and pulsed magnetic field was more stable than the others in Fig. 6(b) with single pulse and steady solenoid. The results show that the stability at the Fraday cup is improved by the improvement of the beam stability from the laser ion source.

Table 2 shows the mean and standar deviation of the total charge within the single beam pulse at each monitor. The statistics was 50. At any positions, the ratios of the standard deviation to the mean were smaller with the next run setting than those with the last run setting. Especially, the ratio at the current transformer 1 was improved from 32 % to 3.4 %. In addition, the ration at the Faraday cup was also improved from 14 % to 6.1 %. The results show that the beam is more stable in the injector line using the double laser pulse and the pulsed solenoid.

Table 2: Mean total charge within a single pulse and the standard deviation at each current transformer (CT) and Faraday cup (FC). The unit is nC.

Conditions	**Next run**		**Last run**	
	Mean	Stdv	Mean	Stdv
CT1	74	4.0	75	24
CT2 at injection	16	0.80	14	3.4
CT2 at extraction	32	1.2	29	4.7
CT3	4.7	0.22	4.3	0.63
FC	3.6	0.22	3.4	0.47

SUMMARY

We compared the standard deviations of the total beam charge in the injector line under two conditions of the laser ion source. Under one condition, the single laser and steady solenoidal magneic field were used as last run. With the other, the two laser and pulsed magnetic field were used as next run setting. We confirmed that the beam stability with next run setting is better than with last run setting.

ACKNOWLEDGMENT

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